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Transforming Intelligence: Improving Inference through Advanced Simulations

Better Prediction through Better Inquiry

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Abstract

Recent enhancements in modeling and simulation techniques offer significant improvements for intelligence analysts to increase their inference and prediction skills. Architectural and programming improvements in techniques known as agent-based models offer analysts opportunities to increase their capabilities to deal with complex masses of evidence. These models demonstrate how the process of discovery may be improved through empowering information observations that compose evidence to interact with each other and with the analyst to drive toward more meaningful lines of inquiry – to increase the likelihood of asking more important questions in situations traditionally thought of as complex and opaque. Biologically inspired models of self-organization motivate the construction of forms of agent-based models that encourage analysts to interact more directly with the evidence they observe and to improve inference and inquiry, as well as prediction. An environment known as Hypothesis and Evidence Reasoning Modeled by Emergence Simulations (HERMES) provides the framework for this development.

Biography of LTC Carl Hunt, National War College

Lieutenant Colonel Carl Hunt, US Army, is currently a student at the United States National War College, Ft. McNair, Washington, DC. LTC Hunt has served 23 years in the United States Army both as a military policeman and as an information systems technology officer. His most recent assignment was as the commander of the US Army Criminal Investigation Command's Computer Crime Investigative Unit. As an Army Information Systems Technology Officer, he developed and managed several advanced technology projects, including the Proteus Project, a joint collaborative communications effort of the United States Army Intelligence and Threat Analysis Center and the national intelligence community. LTC Hunt holds the Ph.D. in Information Technology from George Mason University, and in March, 2003, was selected for promotion to the rank of Colonel. His next assignment will be with the US Strategic Command's Joint Task Force for Computer Network Operations. LTC Hunt is married with one son.

Transforming Intelligence: Improving Inference through Advanced Simulations

Better Prediction through Better Inquiry

Take time off the table. Now consider the evidence before you as objects that must be connected purely in terms of space and non-temporal relationships. Next, assemble the objects of evidence over and over in your mind, building new combinations to see how they might fit. Merely grazing the tip of time you realize that the order in which you encounter and consider these new combinations of evidence strongly influences the way you perceive the potential hypotheses that you would fashion to explain this assemblage of information. Finally, put time back on the table, as we must really live our lives, and see how your explanations ebb and flow around the relationships you built in the absence of time. This is how we learn to think outside the box of temporal linearity, how we learn to fashion new lines of inquiry, and how we learn to predict the next good questions to ask…and answers to expect. This is how we might use ambiguity to our advantage. Such are the ways in which we must build hypotheses in this complex age of uncertainty and predict outcomes from incomplete evidence through better inquiry.[i]

Abductive reasoning is an act of insight…it is putting together what we had never before dreamed of putting together which flashes the new suggestion before our contemplation (Charles S. Peirce).[ii]

The true work of the inventor consists in choosing among these (rules) combinations so as to eliminate the useless ones or rather to avoid the trouble of making them, and the rules which must guide this choice are extremely fine and delicate. It is almost impossible to state them precisely; they are felt rather than formulated (Henri Poincaré).

We need to have some system to perform the logical process of consciously juxtaposing the detailed related ideas, for the purpose of producing rationally a single fixed idea (John H. Wigmore).

1. Introduction. In recent years, two major scholars of evidence and inference have sought to influence the United States intelligence community to consider the way conclusions are reached. David A. Schum and Richards J. Heuer have introduced both academic and common-sense approaches to regard masses of evidence and assess the likely consequences of the emerging events to which the evidence points. Through these reviews of inference and evidence, they have sought to improve the condition of prediction.[iii]

Heuer noted that "analysts should be self-conscious about their reasoning processes. They should think about how they make judgements and reach conclusions, not just about the judgements and conclusions themselves" (1999). Descriptive analysis is necessary but not sufficient to frame insightful prediction in support of complex problem solving – how evidence is interpreted is an important consideration, as well. Twelve years earlier, Schum made a similar case in a two volume work he prepared for the Central Intelligence Agency called *Evidence and Inference for the Intelligence Analyst* (1987).[iv]

Assessing how conclusions are reached in the intelligence disciplines is just as important as the conclusions, and often equally as difficult to explain. That is why prediction has been both the Holy Grail and the booby prize of the intelligence community at the same time. And, technology alone does not promise to resolve this predicament.

Consider for example the introduction of new analytical and decision-support tools. Absent fundamental transformation in the way evidence and hypotheses are integrated in the analyst's mind these technologies serve only to automate less-than-effective processes. Equally troubling, innovation combines newly introduced technologies in ways in which they were never foreseen to work together. Product drives process,[v] capability supplants need, and technology outpaces requirements. Finally, in a problem that also confronts intelligence analysts, hypotheses about product success are often not based on the evidence that confronts producers.

This "innovation" phenomenon applies to the "management" of data, information and knowledge, as well. As the recent attacks on America demonstrate, a significant result of the merger of data and technology is an ever-increasing glut of "information" competing for our attention in ways that are unprecedented in history. Conventional methods for organizing, analyzing and focusing information to support the knowledge requirements of key decision-

makers and commanders likely will not sustain the current situation, as these methods tend to be born of the same models of technological development and introduction.

There are solutions, however, that can immediately come to the aid of the commander and analyst. New modeling technologies are converging with time-tested methods for inference. Simulation-based scenarios comprise the framework for these new decision-support tools.[vi]

Scenario development and interaction, based on modeling techniques that embrace multidisciplinary thinking, embody a relatively new method of simulation: the agent-based model. These techniques are becoming readily available for commanders and analysts.

This paper proposes a modeling and analysis environment called Hypothesis and Evidence Reasoning Modeled by Emergence Simulations (HERMES) to offer perspective and insight in ways to deal with complex decision-making environments and assist commanders in dealing with information overload.

As a process, HERMES offers to assist in transforming the way in which the intelligence community supports commander-focused command and control (C2) planning and execution from the highest strategic levels to the most operationally-focused tactical levels, by providing a consistent architecture and standard framework for information acquisition, analysis and action.[vii] As a tool, HERMES proposes to enhance the way the analyst views evidence, moving from descriptive analysis to interpretive analysis and to enable more reliable prediction.

The quotes at the beginning of this paper set the stage for this research. Analysts must learn to think beyond the constraints of their training and perspective – thinking outside the linear nature of time is one way to expand thinking. Peirce and Poincaré went to great lengths to challenge their readers to embrace the process of discovery and invention of novel ways of thinking; Peirce

even coined a new word, *abduction*, to describe this process of creating new thought.[viii,ix] Wigmore told his readers, primarily law students, that they must develop a system to combine evidence into related thought, in juxtaposition, to arrive at rational ideas.[x] HERMES proposes an environment to accomplish the fusion of these very difficult tasks.

2. Research Issues.

This research poses the following lines of inquiry:

- Can the integration of new methods of modeling and simulation shift the intelligence analyst from descriptive analysis to interpretive analysis?[xi]

- Can interpretative analysis build a better environment for prediction than descriptive analysis?

- Can agent-based modeling and the analyst's interactions with these models enhance the questions that must be asked of the evidence and the new lines of inquiry that must be formed?

- Can the analyst use these models to assist strategic decision-makers find *Ground Truth*?

Figure 1, below, visualizes the relationships between evidence, inference and ground truth.

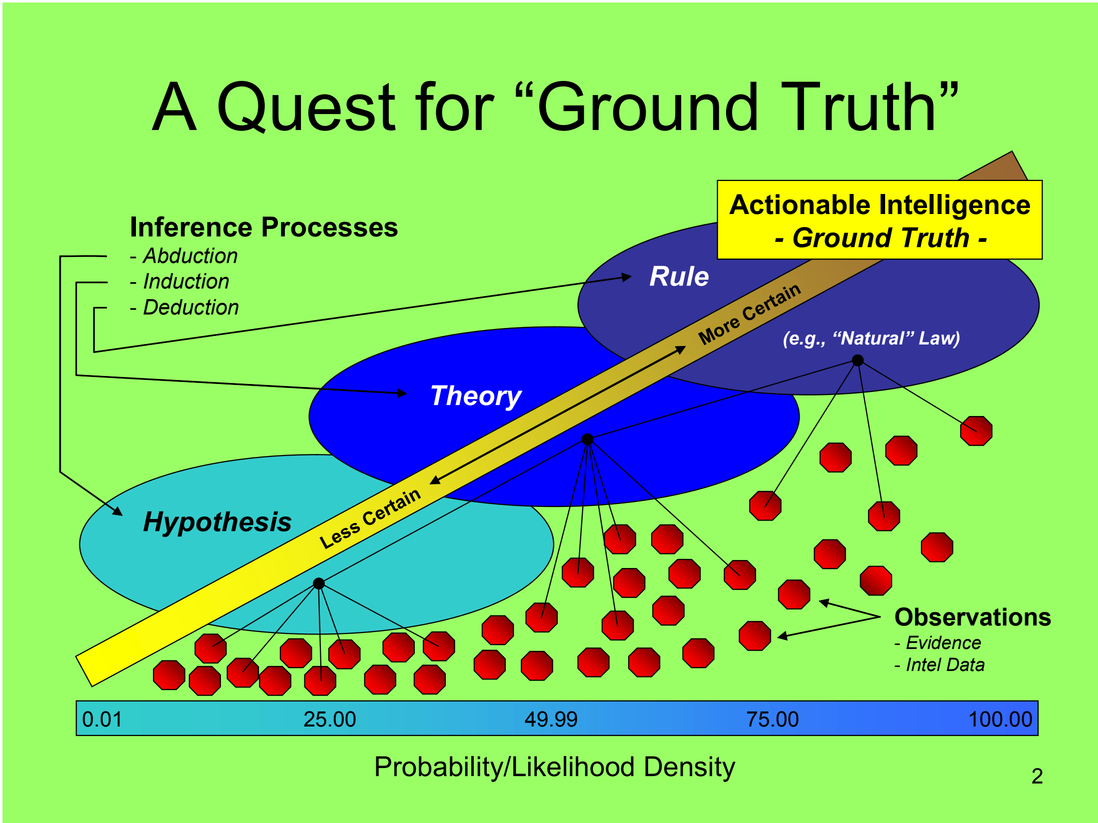

Figure 1. Ground Truth begins at the point where commanders or analysts are confident they can make decisions based on the evidence available to them. Note the inference processes involved in moving from hypothesis to "Ground Truth." Processes are driven by meaningful lines of inquiry, hence the importance of understanding interactions of hypothesis and evidence. See paragraph 4 for a more extensive discussion of the notion of Ground Truth.

Advanced modeling and simulation techniques, using what are known as agent-based models,[xii] can provide new levels of insight into the intelligence community's understanding of the interactions of evidence and hypothesis. Analysis can thus be interpretive and predictive as well as descriptive. Insights can be manifested in terms of novel lines of inquiry or responses to inquiry through visual interaction with these new types of models. From these insights, analysts and decision-makers can better predict emergent outcomes of complex events, while considering how conclusions are reached.

The remainder of this paper addresses three primary areas:

- An overview of complex systems theory and emergence

- An overview of the HERMES modeling environment

- An introductory description of an architecture and proposed class of simulations that could be suitable for discovering new insights from the interactions of evidence and hypotheses.

This approach to modeling complex intelligence problems is consistent with the tenets of Network-Centric Warfare (NCW). "NCW is offered to provide a rich source of hypotheses to be tested and refined, and a conceptual framework to focus the experiments and analyses ahead" (Alberts, et. al., 119). In other words, NCW, also proposed as a means to transform the US military, provides a valuable cognitive framework for considering experimentation and analysis as core tools for improving the way the United States intelligence community conducts analysis and synthesis of evidence and inquiry. The advanced modeling techniques and architecture presented in this paper fully complement what network-centric warfare offers.

3. Complexity Theory and Emergence. It is useful to understand some basic premises of complex systems theory and emergence in order to understand how to construct and comprehend the outcomes of simulation of emergence models.

Complexity Theory. There are several ways to define complexity in relation to complex systems theory, but they typically incorporate two formalized systems of study: chaos theory and complexity theory. Management consultant and Industrial College of the Armed Forces lecturer Irene Sanders provides succinct definitions of chaos and complexity theories in her current lectures and book:

> *Chaos theory describes how a sensitive dependence on initial conditions contains the potential for change through (what is known as) the Butterfly Effect.*[xiii] *Complexity theory describes how order and structure arise through the process of adaptation set in motion by new information, which tips the balance and pushes the system into a chaotic episode…complexity theory incorporates and depends upon the details of chaos theory…(while chaos theory) is the mechanism through which change is initiated and*

> *organized. It is the way the world creates the rich diversity that we see all around us.* (Sanders, 69-70).

The study of complexity may also be likened to the study of life and the environment in which life exists. Think of complex behavior as one hierarchical step above the interactions of simpler actors (or agents) such that the higher-level behaviors are richer in content and context. Complexity deals with how living and "non-living" environmental entities interact with, or coevolve with each other to produce the behaviors that can ultimately be observed. Organizations, particularly those composed of people, also produce complex and often unpredictable behaviors; some of these behaviors lead to innovation. Several complexity authors, including Sanders and Kauffman, speculate that a rich transformation zone for innovation lies in a notional space called the *edge of chaos*.[xiv]

To change an entity that is frozen into an ordered state, according to Sander's definition, it may be necessary to unfreeze the entity through the introduction of some sort of chaotic phenomenon. If it were possible to control such changes (such as innovation or transformation) it would be desirable to have a launching pad or transition zone to observe and tweak these introductions of chaotic behavior to avoid a cascade into system-wide uncontrollable behaviors. The so-called edge of chaos seems to identify this "place" for experimentation. It would likely not be possible to accurately predict the outcomes of the introduction of these chaotic tweaks, so novelty and innovative behaviors may thus be thought of as *emergent*.

Emergence. The study of emergence "tries to generate the properties of the whole from an understanding of the parts," and thus offers the potential for deeper understanding of complex systems, notes George Mason University biologist Harold Morowitz (14). Emergence reflects

new levels of organization or structure that could not have been previously predicted from observation of the individual parts of the organization alone (Hunt, 11).

In a sense, complexity is part of the definition of emergence and emergence is part of the definition of complexity. These definitions are manifested in the difference between complex and complicated – words that are often but incorrectly substituted for each other. There is a distinct difference between something that is complex and something that is complicated. Paul Cilliers notes the differences succinctly:

> Something that is *complicated* can have many components, and can be quite intricate, but the relationships between the components are fixed and clearly defined…Something that is *complex* on the other hand, is constituted through a large number of dynamic, nonlinear interactions…complex things have emergent properties, complicated things do not. (Cilliers, 41).

Cilliers points out that when the relationships between components of complex systems are broken (e.g., in disassembly), "the important characteristics of a complex system are destroyed." This is not the case in complicated systems which often require analytic breakdowns to understand system behaviors (*ibid*.). Emergence is the key difference between complex systems and complicated systems.

Coevolution is also a relevant component for this brief overview of complex systems theory. Kauffman notes that evolution is really coevolution in the sense that entities or systems do not evolve in a vacuum. In a Darwinian sense, evolution is an adaptation to some external stimulus that forces change to occur in order to survive or be in position to improve one's standing on the "food chain" of life (Kauffman, 222).[xv] Changes in one system typically stimulate change in adjacent systems or environments – the essence of coevolution. Evidence and hypotheses coevolve with each other and their environment to produce new and productive lines of inquiry.

HERMES focuses on the premise that emergent complexity arising out of simple but coevolving environments produces richer insight for a human decision-maker or analyst. This is opposed to typical attempts to engineer the "perfect" knowledge management solution from the beginning. An emergence approach means that discovery is possible simply by observing the interactions and learning that take place within the body of evidence. Consider that the analyst becomes a synergistic part of the interactive process, building the environment and engaging in the emergent inquiry process. Pieces (or objects) of information, encoded as agents (as described below) that can learn and act on their own behalf as well as on behalf of the analyst, can become more revealing than simply finding a "golden nugget" or "silver bullet."

These often sought-after nuggets or objects of information may be meaningless or unrecognizable without the context of interaction: *process and product must be considered simultaneously*. HERMES and simulation of emergence models such as ABEM empower discovery of context and seek to visualize the richness of complexity that arises from the interactions. Complexity, as an emergent property, becomes a desirable trait rather than something to be avoided.

Figure 2, below, visualizes this process in terms of what physicists call a phase transition where objects or a collection of objects change state, like water changing to ice or steam. In this drawing, combinations of evidence objects change state from loose collections of information to richer regions of insight and a potential economy of solutions. The "golden nuggets" do not lose their value, but become even more meaningful when visualized within their contextual environment. Throughout the process, the analyst becomes more intimately involved with the flow of information and discovery of new knowledge that emerges.

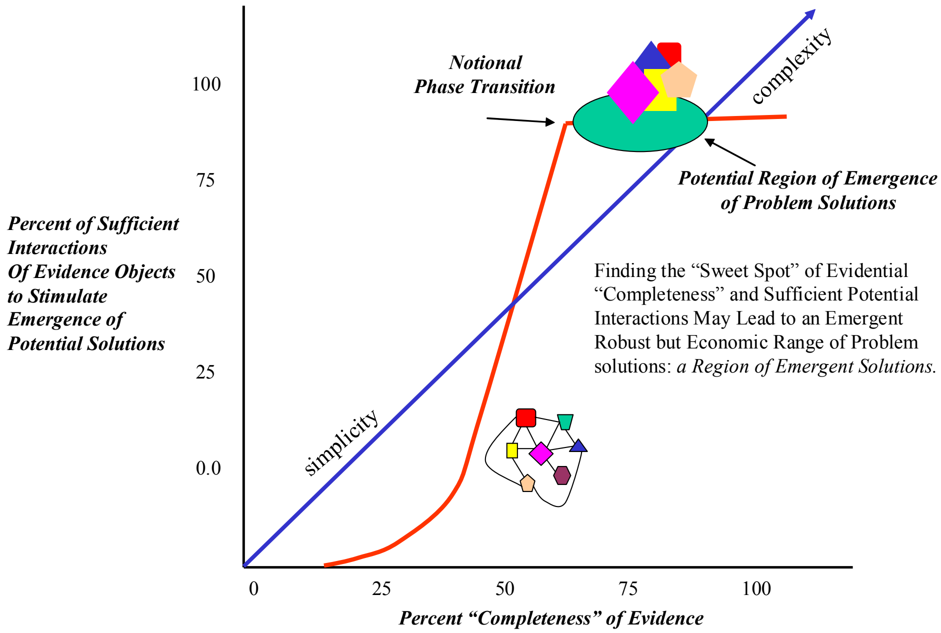

Figure 2, "Complex Emergence." This drawing depicts how an analyst may map a region of possible solutions that emerge through rich interactions of evidence, once a sufficient amount of evidence has been obtained. The thesis of this drawing is that once there exists a sufficiently "complete" set of evidence observations, and these observations have been empowered to interact in an emergent modeling environment for a "sufficient" amount of time, there will occur a phase transition that produces an environment for the evolution of a region of possible problem solutions. As occurrence of interactions of evidence proceed up the slope to this region (e.g., increasing), solutions progress from simple to complex, with the more complex solutions offering robustness in potential alternative solutions and richness of explanation that encompass relevant critical items of evidence. An economy of solutions emerges that provides the analyst with meaningful new directions for inquiry and hypothesis. "Golden nuggets" and "silver bullets" do not lose their value, but stand out within the context of their interactions with other evidence (Hunt, 2001).

Traditional analytical descriptive and engineering approaches can ignore the innovations of emergence, phase transitions and complex adaptive systems behavior. This is not unlike military planning that tries to foresee and accommodate every contingency and that may miss what could happen in the seams between the "foreseen". Complex systems thinking offers valuable ways of considering observed behavior and deducing the linkages and interactions of components that produced the behavior. Broader thinking is the "hidden agenda" when considering emergence.

4. The HERMES Modeling Environment.

a. The Quest for Ground Truth and agent-based modeling.

HERMES offers an enhanced process of inquiry to assist the intelligence and military communities in making better sense of masses of data as they represent observations of human and machine-based sensors. *Ground Truth* serves as a proxy term to describe sufficient knowledge to confidently make decisions that support some action. Nature produces its reality, or ground truth, through self-organization and emergence, based on the equivalent of asking "the right questions." Self-organized data can conceivably assist analysts in discovering rules or laws that allow for more certainty in environments of incomplete knowledge: ground truth.

Nature provides the example for the implementation of the HERMES process. The agent-based model is meaningful way to model nature. Agent-based modeling (ABM) is the primary tool for visualizing complex relationships between evidence and eventual ground truth that leads to decision or action. These models are useful for simulating and visualizing emergence.

ABM embodies real-world environments that allow for leaders to picture the relationships between entities. Each entity reflects agency, or self-directed behavior that interacts in an environment suitable to reflect behavior. These behaviors may be so finitely pre-specified as to preclude novelty, or, towards a more meaningful outcome, sufficiently programmed to allow for emergent behaviors to occur. Agents are software representations of real or possible entities that are constructed to reflect possible or potential outcomes of interaction. Rules are embedded in the simulation to provide realistic and relevant boundaries for emergent behavior.

An early application of agent-based modeling that captures the emergence of relationships between evidence and hypothesis is the Agent Based Evidence Marshaling (ABEM) model, shown below, in Figure 3. ABEM follows a biological model akin to protein synthesis that empowers information objects to find relationships between themselves. Such techniques allow for dynamic visualization of interactions and greater potential for discovery within obscured or

complex datasets. As in nature's model, inquiry is fundamental to success. Complexity arising from simplicity is revealing.

ABEM was introduced specifically to assist analysts and investigators visualize complex relationships and the emergence of the interactions of evidence and hypotheses. Its core architecture is geared towards empowering the process of discovery and assisting in the marshaling of evidence (juxtaposing, as Wigmore wrote).

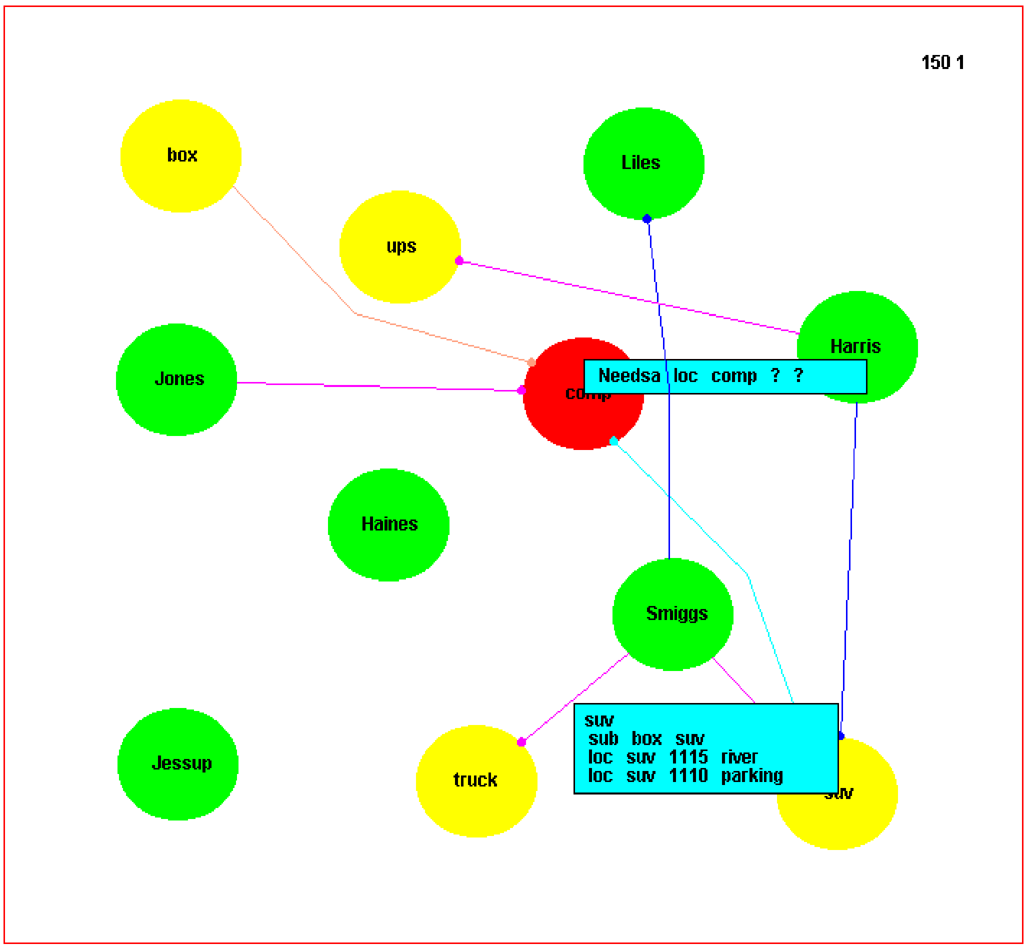

Figure 3, the Agent Based Evidence Marshaling (ABEM) Model. This model depicts self-organizing linkages between individual items of evidence that depict the results of inquiry during an investigation. Through simple inquiry, information objects interact and learn of critical relationships that result in the human investigator observing insightful complexity in the form of global knowledge rising out of locally known information. The rounded shapes depict individual agents. The rectangular shapes represent queries and the storage of information relevant to an agent (see Hunt, 2001).

The basic theme of the ABEM model shown above is to empower agents with local knowledge about a matter under investigation and provide an environment for them to discover more globally emergent knowledge through interactions with other agents and the human investigator. ABEM agents are thus a surrogate learning device for the analyst or decision-maker. In the ABEM visualization of figure 3, agents are depicted as various colored circles (nodes), and the emergent relationships between them are shown as arcs between the circles. The red (darker colored) agent shown above represents a government computer which has been stolen. The other agents represent either human witnesses with some limited information about the theft, or inanimate objects that may have been used in the crime or "witnessed" the crime.[xvi]

All ABEM agents are treated equally in the sense that they have constrained initial knowledge about a given problem and can communicate with each other through simple query and response in terms of time and location. The agents are programmed to be very curious about themselves and to learn their place in the ABEM world. The computer agent's mission, for example is to learn for itself a time-space vector of its existence from the time it was stolen to the time it was recovered. The arcs between agents also emerge as the agents discover relevant relationships about themselves. The agents are capable of inferring the importance of other agents to their own vector through a mechanism known as substitution, described below.

Ground truth is not typically the result of finding the golden nugget in isolation. In most cases, a decision-maker requires context to recognize what the golden nugget even looks like, much less what it means. Interactions of evidence provide context. Inquiry drives interaction. The process of inquiry may be analyst-driven or self-driven as in the case of ABEM, or as a combination of both as suggested by the HERMES process. The agents of ABEM learn in two important ways: the agents ask questions of each other and they ask questions of the human investigator

interacting with the model. The quest for ground truth becomes a complimentary process where the analyst and the agents interact in self-organizing and self-directed fashion, much as life itself has evolved and developed self-sustaining qualities.

Reconsider figure 1 in context with figure 3. These depictions demonstrate the notion of emergent complexity as a product of interactions of simpler objects. As an investigator or analyst encounters and tests more and more evidence about a given question, she is able to attain increasing confidence in resolving the problem. From initial lines of inquiry, or hypothesis as shown in this model, an analyst moves toward greater certainty or assurance about being able to discover rules or natural laws that explain the behavior she first observed.

This does not abrogate the deepest principles of the scientific method – analysts must always test their hypotheses and evidence in ways that lead toward elimination of incorrect paths, not toward confirming only the most favored hypotheses. As many great evidence theorists have pointed out, an analyst cannot simply decide on a hypothesis and seek only evidence that supports it. Testing with an eye toward elimination produces the fitter hypothesis. The cautions of Heuer and Schum are more relevant than ever.

The analyst's inference process begins with an abduction as a possible explanation, moves toward induction and theory based on the accumulation of more evidence, and finally arrives at being able to deduce new evidence that composes the ultimate or authoritative explanation of the problem (see also Schum, 1994). The probability of uncovering ground truth increases as more meaningful evidence and evidential interactions are confirmed through testing and simulation. Complexity emerges rather than being engineered into the model from the beginning.

b. The Growth of Complexity.

In the agent-based modeling world that includes ABEM, the simple objects that interact to produce complexity are called agents. Agents in this context represent information or data objects. The objects are encodings of observations from nature. Observations of nature in the military and intelligence world would also include data that investigators or analysts accrue from sensors or interactions with other people, such as HUMINT sources.

An example from the unclassified world of criminal investigations, depicted in Figure 3, includes the results of interviews and observations by a human investigator.[xvii] In the basic scenario of ABEM depicted above, an investigator interacted with witnesses and observations of evidential phenomena. The evidence encoded by the investigator included such items as tire tracks and weather conditions to inform the software object-agents, as well as noting simple descriptions of the witness testimony. Analysts as modelers can "enhance" their models by treating living and non-living information objects as equals such that all of these objects can interact within the same environmental rule base, if desired.

In keeping with the idea of discovery enhanced by emergence, ABEM agents were imbued with observations from nature, hence the importance of semiotics in the HERMES approach.[xviii] Nature relies on codes to grow and evolve. Master semioticians such as genomic researchers are discovering the codes that make life successful. Natural information systems like DNA can provide inspiration for the construction of information systems technologies.

Apart from modeling information processing in ways that are similar to DNA replication and protein synthesis, HERMES employs the applications of substitution and complementation, first suggested as potential enhancements to information relationships by Kauffman (Kauffman, 1995, 2000). Think of a substitute as an object (or even a thought) that can stand in for another object

(a philosopher might use metaphor as it applies to thoughts or ideas). As Kauffman notes, a screw might be a substitute for a nail in some applications.[xix]

The same basic inferential principles may apply to Kauffman's ideas about complements. According to Kauffman's example, a hammer complements a nail, while a screwdriver complements a screw. The hammer makes it possible to employ the nail, as the screwdriver makes it possible to connect objects with a screw. As they are one layer of abstraction removed, however, it would be rare, but possible, to find a screwdriver as a substitute for a hammer, in spite of their complements positioned as substitutes. In discovering, through emergence, the inferential relationships that might exist between objects at various hierarchical levels, an analyst may learn new lines of inquiry that she did not think of before, leading to that one important instance of when a screwdriver might substitute for a hammer.

Now, think of the hammer or screwdriver as an aspiring pilot who says he only wants to know how to fly in mid-air, not take-off and land, complemented by the desirability as targets of great American landmarks. In an emergent, discovery-based information system might these complementary and substitutionary relationships come to light? Perhaps so, if the analyst discovers, interprets and pursues the right line of inquiry – the underlying theme of HERMES.

Before moving to the ABEM architecture, it is useful to consider the underlying "structure" of ABEM – the technology graph. "A set of primitive parts and the transformation of those parts into other objects is a technology graph," notes Stuart Kauffman, the inventor. "Technology graphs concern objects and actions, things and objectives, products and processes in a single framework," he noted (2000, 254). To express this idea, Kauffman claims also to have "invented" *Lego® World*, using the well-known plastic bricks as examples (*ibid*.).

Regardless of its origins, Kauffman did demonstrate an extremely important idea with *Legos* and the environments one of any age can build with them: component objects, when allowed to interact, transform into typically more complex (and often) larger objects. The technology graph-based ABEM seeks to do precisely the same thing: transform evidence, via interaction, into complex scenarios, theory and eventually testable hypotheses. In the ABEM framework, "objects and actions…" are simultaneously nurtured, and, through autonomous interaction, move towards the eventual goal of posing better questions by discovering what is already collected within the evidential database, and predicting what should be contained within it.

5. The ABEM Architecture.

As a transformational concept, HERMES and ABEM are more than mere proposals. ABEM is the cornerstone technology of HERMES as it exists today. The ABEM screenshot depicted in Figure 3 is based on a documented architecture that is still undergoing development and refinement. This architecture is shown in Figure 4, below, followed by a brief description of its component parts and interactions.

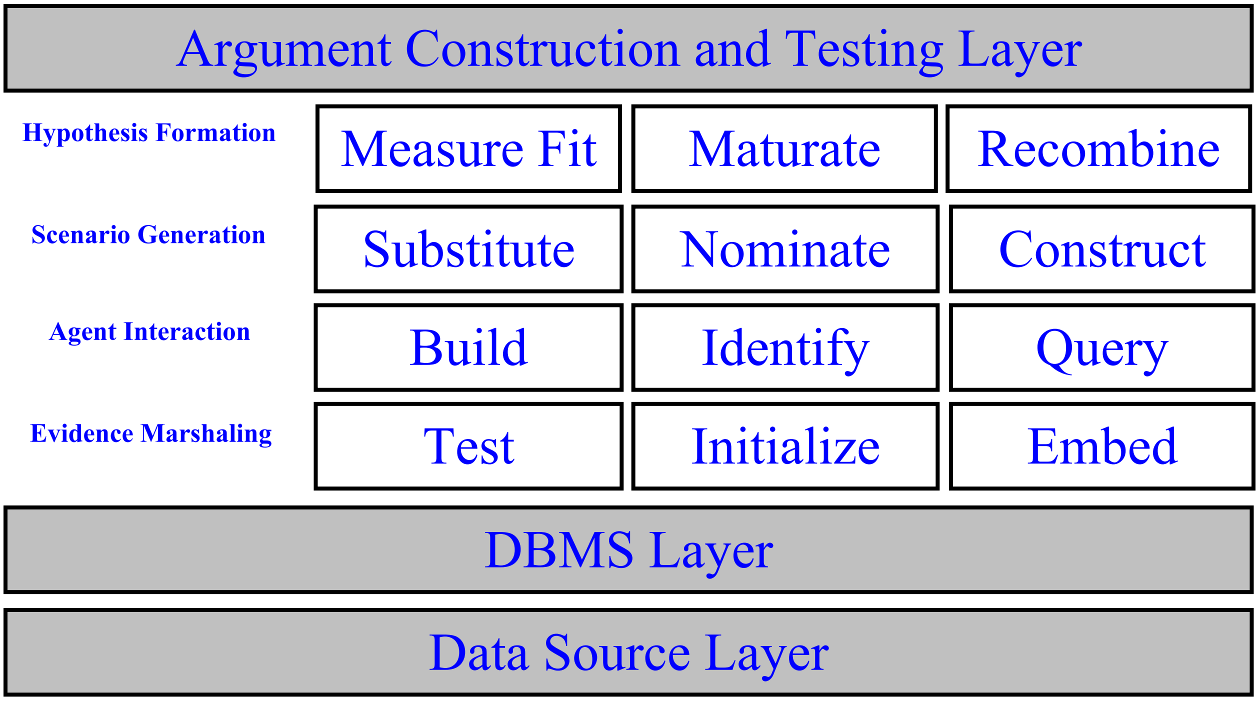

Figure 4. The ABEM Architecture. This drawing depicts relevant processes that influence the transmittal of information from one layer to another as well as between processes, as described below. The goal of ABEM is to empower information extracted from various data sources to mature through a self-organizing process that eventually results in valid and cogent arguments that may be articulated coherently to a decision-maker. The Evidence Marshaling, Agent Interaction and Scenario Generation Layers are described briefly below and in detail in Hunt, 2001. The higher layers, Hypothesis Formation and the Argument Construction and Testing Layers are under development by Stuart Kauffman, Bruce Sawhill and Jim Herriot (as proposed and discussed in Kauffman, 2000).

A brief description of the ABEM architecture begins at the Data Source Layer. This layer represents various existing and emerging methods for storing and processing data inputs such that information content can eventually be extracted. At this stage, data has not been processed or analyzed in great detail, but only collected and tentatively "organized" in traditional database formats. Processing and manipulation of data for more extensive analysis and transfer to compatible record extraction occurs at the DBMS (Data Base Management System) Level.

The Evidence Marshaling Layer captures the original work of David Schum and Peter Tillers in their *MarshalPlan* system (Schum, 1999). The components of this layer include testing, initializing and embedding information for the remaining layers. Testing deals with the first

point at which an investigator or analyst thinks of information as evidence. It includes an examination of the candidate evidence item's credentials such as relevancy and reliability to ensure the information is suitable for use as evidence.[xx]

Once found to be acceptable, the system accommodates the Initialization of the evidence, which includes verifying relevant details and extracting suitable components of it to be used in tuple format, the *lingua franca* of ABEM agent communications.[xxi] Finally in this level, ABEM embeds the initialized evidence into a form suitable for tuple-based communications and agent-based learning that occurs in the ABEM simulation.

The next major ABEM architecture level is called the Agent Interaction Layer. The first component is the Build process, which accepts the marshaled evidence observations and constructs object-agents from these observations. It is at this point that evidence observations enter the object-oriented world of technology graphs and can become part of the transaction-based movements the tuples accommodate. Next is the Identify component. In this process, ABEM tuples are used to satisfy what appears to be a vast hunger for self-knowledge on the part of ABEM agents. Through this subjective process (accompanied by the substitution capability described below), agents actually learn a great deal of information about not only themselves but other agents who become important to them.

Working hand-in-hand, the Identify and Query components reflect the learning process of ABEM agents. The questions agents ask each other are based on attempting to build a more complete space-time vector for themselves, hence the advantage of coding ABEM tuples in terms of space and time for this iteration of the model. Without "understanding" where this space-time vector might logically terminate, the agents nonetheless seek information about

where they may have been inside their virtual world, including tracking space-time vectors of other agents once they "infer" some relationship to themselves.

Agent inference is an important concept of the ABEM architecture and working models. The Scenario Generation Layer empowers inference and learning on the part of the agents. The first sub-component of the Scenario Generation Layer is Substitution. The concept of Substitution is related closely to Kauffman's description of substitutes (and complements), as discussed in Kauffman (2000). It is also related to what artificial intelligence pioneer Marvin Minsky calls "multiple representations" when expressing what he calls "commonsense thinking" (Minsky, 71). As Minsky writes:

> If you understand something in only one way, then you scarcely understand it at all because when something goes wrong, you'll have nowhere to go. But if you use several representations, each integrated with its set of related pieces of knowledge, then when one of them fails you can switch to another. You can turn ideas around in your mind to examine them from different perspectives until you find one that works for you. And that's what we mean by thinking! (Minsky, 67).

ABEM substitution does not pretend to empower machine thinking, but it does allow the analyst to observe data representation from different perspectives as the object-agents seek substitutes for themselves during the query process. Figure 5 depicts an ABEM screenshot where a substitution tuple message both asks and responds to an agent query.

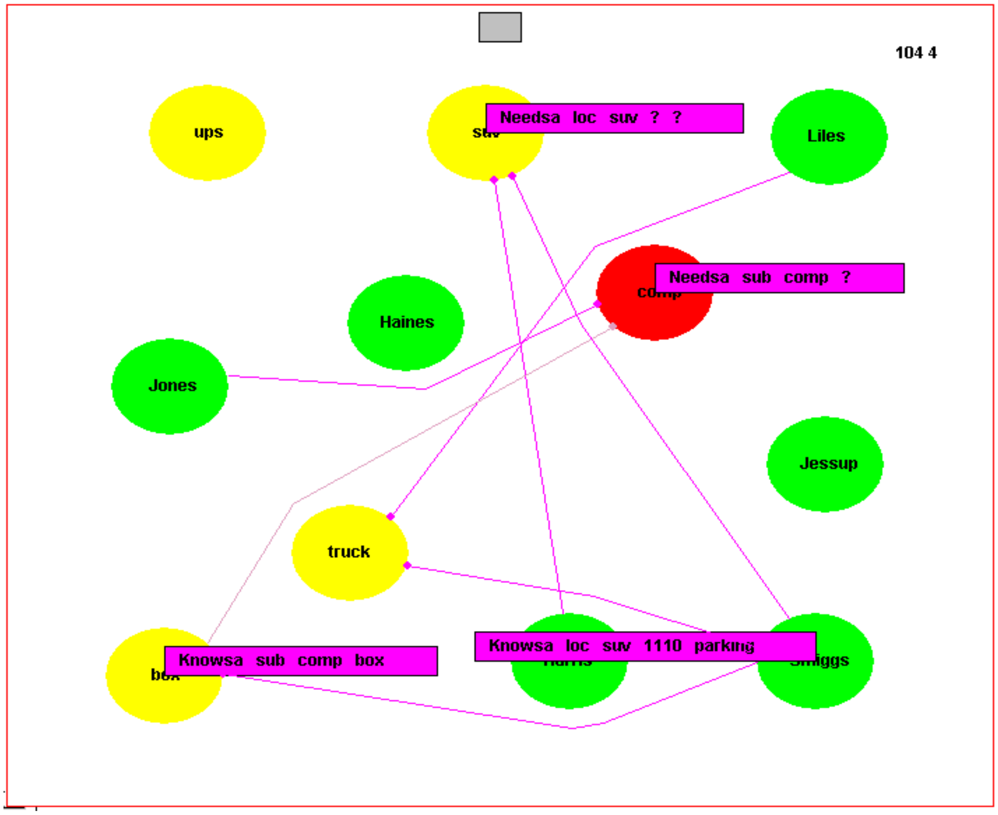

Figure 5. ABEM screenshot. This screenshot from an ABEM simulation depicts the two major tuple-based queries that ABEM agents utilize. At the top center portion is the "SUV" agent asking the "Harris" agent if it knows a location (called loc in the tuple) for itself (an agent-based representation of a sport utility vehicle; "Harris" is an agent-based representation of a witness to a crime). The two question marks concluding the query are placeholders asking for information that pertains to time and space, respectively. The second type of ABEM tuple-based query is a substitution query as described above. In this instance the "computer" agent in the middle right of the screenshot is asking the "box" agent if it knows if there is a substitute for it (called "sub" in the tuple). The "box" agent responds back to the "computer" agent that it knows that it (box) can be a substitute for the computer. In the case of this particular simulation, the box is capable of holding (or concealing, in the case of a deception) the computer. In other words, where the "box" agent is in space and time becomes an important bit of knowledge for the "computer" agent that is trying to piece together its own time-space vector. In Minksy's terms, the "computer" agent can have "multiple representations" in what would otherwise be a very linear vector. Agent-based models such as ABEM empower analysts to visualize outside the traditional vectors that appear grounded in obvious cause-and-effect relationships. These types of models help decision-makers test hypotheses that don't neatly fit within conventional relationships among objects.

The next component is the Nominate process. Quite simply, the nomination process of ABEM involves the introduction of a new, yet to be discovered evidence object that helps to hold a place for potential evidence. In his description of the *MarshalPlan*, Schum referred to these placeholders as "gap fillers" (Schum, 1999). The ABEM process of nomination serves as the

"temporary" filler until the relevant evidence observation is made. Nomination empowers deduction and potential prediction of what to look for and even where to find it.

Construction is the final component of the Scenario Generation Layer. In the current implementation of ABEM this is an analyst-driven intuitive process that results in the construction or development of likely scenarios of what transpired or could transpire based on the interactions of ABEM agents. Out of scenario generation, the analyst builds and tests hypotheses (or questions) about the evidence or environment that has not yet been made clear. Scenarios provide glimpses of what is possible and what needs to be known to become more certain about the matter in question.

There are two remaining layers in the ABEM architecture. Although the Hypothesis Formation Layer is not well developed at this point, it is clearly an important direction in which to extend this work. Its three components include measurements of fitness, maturation and recombination. By providing emerging and developing hypotheses unique methods of identification similar to the genomes of living systems, hypotheses can potentially "recognize" each other and what may be important to their existence and growth. Tuples and agents are components of these genomes. Genomes offer constructs which can be measured and positioned in hierarchies that demonstrate fitness. This is the thrust of the theory behind fitness measurement in ABEM.

Maturation is simply a process of empowering interaction and nurture through the movement of evidence and hypotheses around a virtual ABEM landscape. The proposed ABEM landscape provides sustenance in terms of evidence and inference factors that assist in maturing the developing hypotheses (Hunt, 2001). Recombination is a proposed feature that allows existing hypotheses to "collide" and swap their equivalent "genetic material" in ways that evidence items may be transferred in context by means that had not been observed in the real world. Both of

these features are derived from the benefits of the simulation capabilities of agent-based models like ABEM. While little modeling work has been done in this layer, great potential for discovery exists by extending the ABEM work in this direction.

The final part of the ABEM architecture is Argument Construction and Testing Layer. No single piece of evidence stands on its own. Evidence must be considered in context with other pieces of evidence and the lines of inquiry they suggest. To convince a decision-maker about the effective use of evidence an argument must be successfully presented and debated or tested. Decision-makers must understand the arguments analysts pose to them. The evidence analysts seek to support their arguments are strongly influenced by the order in which they have previously learned information. Presentation and testing infuses the rigor of the scientific method into decision-making. Schum (1994, 1999) lays out both theoretical and practical considerations for constructing and testing arguments that would be essential to incorporate into more sophisticated versions of ABEM.

6. Conclusions.

All analysts and decision-makers are influenced by the constraints in which they see themselves. These constraints are frequently called “boxes.” There are often physical reasons why these boxes exist, but the power of virtual worlds such as agent-based modeling environments that accommodate the visualization of emergence and interaction can serve to deliver analysts from many of these types of constraints. Interpretation and prediction can enhance description.

Prediction that “positively” foretells the future is reserved for powers that exceed the human intellect. Prediction that maps a course for better understanding of what is possible and queuing sensors to observe early indications of events is completely within the realm of the human analyst, however. Predictive capabilities such as these demand more than simple analysis.

Information and evidence must be interpreted. Inference must lead to visualization of what is likely to occur in the future.

Effective interpretation and prediction transforms the world of not only the intelligence analyst but the world of the decision-maker who must commit the resources of the nation to achieve its objectives. Technological tools will not accomplish this alone. With transformation of thought that accompanies new tools, analytical intelligence support to commanders at all levels may be vastly improved. Analysts must consider the process as well as the product.

HERMES proposes to empower analysts using existing information technologies with the capability to think beyond existing constraints, and transform the way the intelligence analyst examines and considers evidence. While HERMES and ABEM admittedly employ contrived enhancements to mimic little understood processes, these devices are likely only temporary until greater understanding of the physical and metaphysical world occurs.

As a proposal to assist in the transformation of the US intelligence community's ability to analyze evidence both descriptively and interpretively, HERMES would extend the ABEM work to enhance the growth of complexity in ways that are positive and illuminating to the analyst. From the simplest associations of data within self-organized information objects could grow rich complexity, patterned after nature's own highly successful models and codes.

Asking better questions sets the stage for better comprehension of a complex world. Better inquiry leads to enhanced capabilities to predict, given human intellectual constraints. Visualizing the interactions of evidence and the questions the interactions raise improves the way the US intelligence community understands the environment. As a setting to assess evidence and hypotheses, as well as product and process, HERMES is a path to continue this transformation.

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NOTES

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[i] This quote is extracted from a working manuscript by the author dealing with the integration of contemporary inference techniques and emerging inference techniques empowered by the Agent Based Evidence Marshaling model discussed below.

[ii] "Abductive reasoning" is a term proposed by Peirce as a third method of inference to demonstrate how ideas initially come to exist in the mind. Peirce spoke of deduction and induction as traditional inference methods.

[iii] Evidence, as used in this paper to describe pertinent information, follows the legal definitions of US Federal Rules of Evidence (FRE 401), which considers the following: "'Relevant evidence' means evidence having any tendency to make the existence of any fact that is of consequence to the determination of the action more probable or less probable than it would be without the evidence" (FRE 401). In this sense, evidence is relevant information that influences a legal proceeding or some sort of decision-making process such as done by an analyst or commander.

[iv] Schum has updated this work with Frank Hughes in Hughes, Frank J., and Schum, David A., *The Art and Science of the Process of Intelligence Analysis*, a text for the Joint Military Intelligence College, Defense Intelligence Agency, Washington, D.C., 2003.

[v] Consistent with the issues raised by Schum and Heuer noted above, product is often considered apart from the process which was used to derive it. A recently proposed agent-based modeling tool invented by Stuart Kauffman known as the technology graph offers a way in which to visualize and consider process and product simultaneously. Technology graphs are discussed in paragraph 4.

[vi] Modeling scenarios can be of immense value in evaluating information and relationships of that information to various C2-related environmental constraints. The methods by which we construct and interact with scenarios must be subject to constant review, however. The admonitions of Schum and Heuer apply.

[vii] The basic architecture in support of HERMES is found in the Agent Based Evidence Marshaling (ABEM) model described below.

[viii] For more insight about the works of Charles S. Peirce, see *The Essential Peirce*, a two volume set, Indiana University Press, 1992 and 1998.

[ix] See also Poincaré, H., *The Value of Science*, 2001.

[x] See also Anderson, T. and Twining, W., *Analysis of Evidence*, 1991, for "modern" uses of Wigmore's work.

[xi] Where descriptive analysis is characterized by *simple* (if complicated) relationships between evidence and hypotheses, and interpretive analysis is characterized by *complex* relationships between evidence and hypotheses. The distinctions are discussed at greater length in paragraph 3, but the primary difference is found in the concept of emergence, also described in paragraph 3.

[xii] As an initial definition of the agent-based modeling concept think of agents as software representations of real or possible entities that are constructed to reflect possible or potential outcomes of interaction enabled by the programming environment that contains the agents. This definition is expanded in sections 4 and 5.

[xiii] The *Butterfly Effect* refers to the way small changes in what were once thought of as linear systems can produce unpredictable and sometimes wildly fluctuating behaviors in systems. Chaos theory pioneer Edward Lorenz is credited for posing the example that a butterfly flapping its wings in one part of the world could ultimately be responsible for a hurricane or tornado somewhere else in the world. See Sanders, pp. 53-61.

[xiv] The *edge of chaos* is said to exist in a transition state between rigid order and a chaotic condition (See Kauffman, 1995, pp. 26-29, and compare with Sanders' discussions about the interfaces of chaos and complexity, in section 3.).

[xv] Morowitz goes even further, noting that "all evolution is coevolution," (183).

[xvi] This description of ABEM is based on the scenario in which ABEM debuted in 2001. The scenario dealt with the theft of government equipment, a computer, in order to present the model in an unclassified environment.

[xvii] As pointed out in paragraph 3, the instantiation of the original ABEM work was in fact a simple example scenario of a case of theft, although misdirection and missing details were interwoven into the example (see Hunt, 2001).

[xviii] Semiotics is the study of signs and systems that produce signs. The study of semantics, and its concomitant search for meaning, is a type of semiotics. Sherlock Holmes, the great detective created by Arthur Conan Doyle, is often cited as one of the great semioticians of literature, paying close attention to the details of nature.

[xix] See Hunt, 2001 for details about modeling these concepts

[xx] For a detailed discussion on the credentials of evidence see Schum, 1994.

[xxi] Tuples in ABEM are patterned after David Glertner's pioneering work in message passing between database objects – they are essentially fields or "rows" from a database, in the way that Glertner introduced them. Tuples were adapted for use in the ABEM environment by Bios Group Scientist Jim Herriot (Hunt, 2001), who built in the time-space orientation for message passing. Examples of tuples in action appear in the ABEM in Figure 5.